National Aeronautics and Space Administration

UAS INTEGRATION INTO THE US NATIONAL AIRSPACE

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University of California Berkley Lecture April 2016

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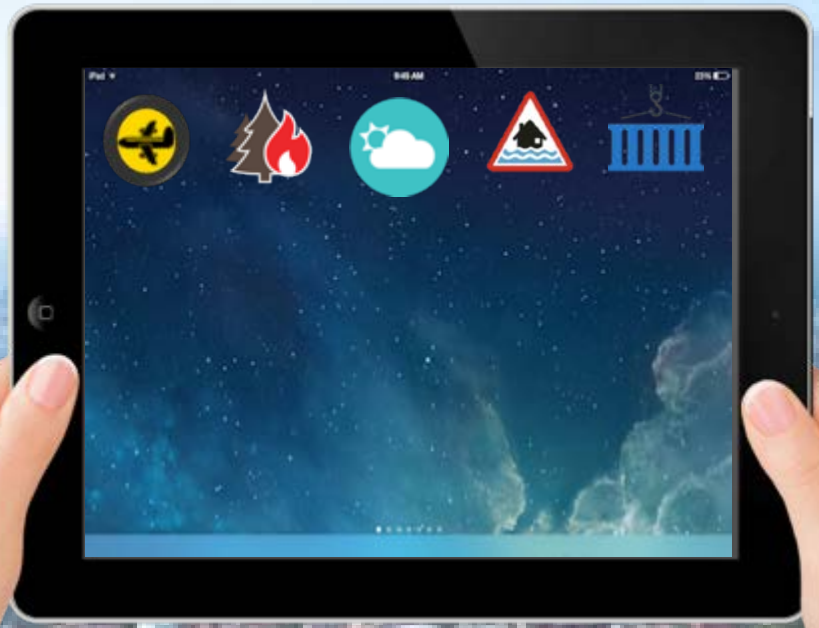
Consumer

Public Service

Commercial

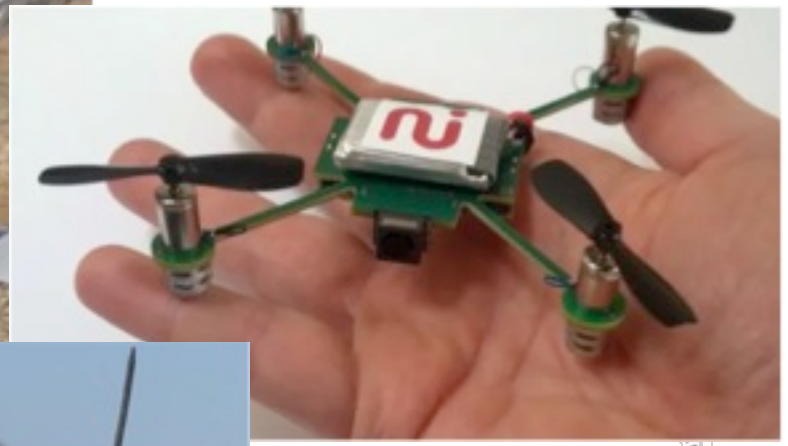



Safety Security Privacy

What is a UAS?

- **An Unmanned Aircraft System (UAS) historically has had various names**
  - Drone, ROA, RPA, UAV, Model/R-C
- **UAS come in all kinds of shapes & sizes**
- **UAS have many uses**
  - Agricultural to Zoological
- **UAS have many different users**
  - Government entities
  - Universities

UAS come in all shapes and sizes



UAS Classifications

- By US Military Group
- By Location
- By Physical Size
- By Weight
  - Weight vs Altitude
- By Endurance
  - Endurance vs Weight
  - Endurance vs Altitude
  - Endurance vs Payload
- By Altitude
  - Altitude vs Speed
- By Wing Loading
- By Engine Type
- By Range/Altitude
- By Performance
- By Capabilities
- By Type
  - Micro
  - Small
  - Medium Altitude Long Endurance (MALE)
  - High Altitude Long Endurance (HALE)
- International Classifications

UAS is a “System”

Command, Control and Communication Links

Unmanned Aircraft and Payload

Ground Control Station

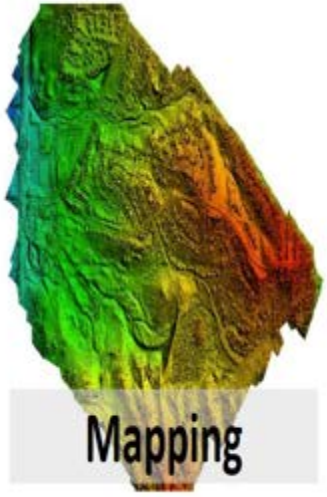
UAS Sensors and Payloads

- Electro Optical (EO)
- Infrared (IR)
- Infrared Linescan (IRLS)
- Multi Spectral Imaging (MSI)
- Hyper Spectral Imaging (HSI)
- Light Detection & Ranging (LIDAR)
- Laser Radar (LADAR)
- Chemical, Biological, Radiological & Nuclear (CBRN) Detection
- Synthetic Aperture Radar (SAR)
- Moving Target Indication (MTI)
- Signals Intelligence (SIGINT)

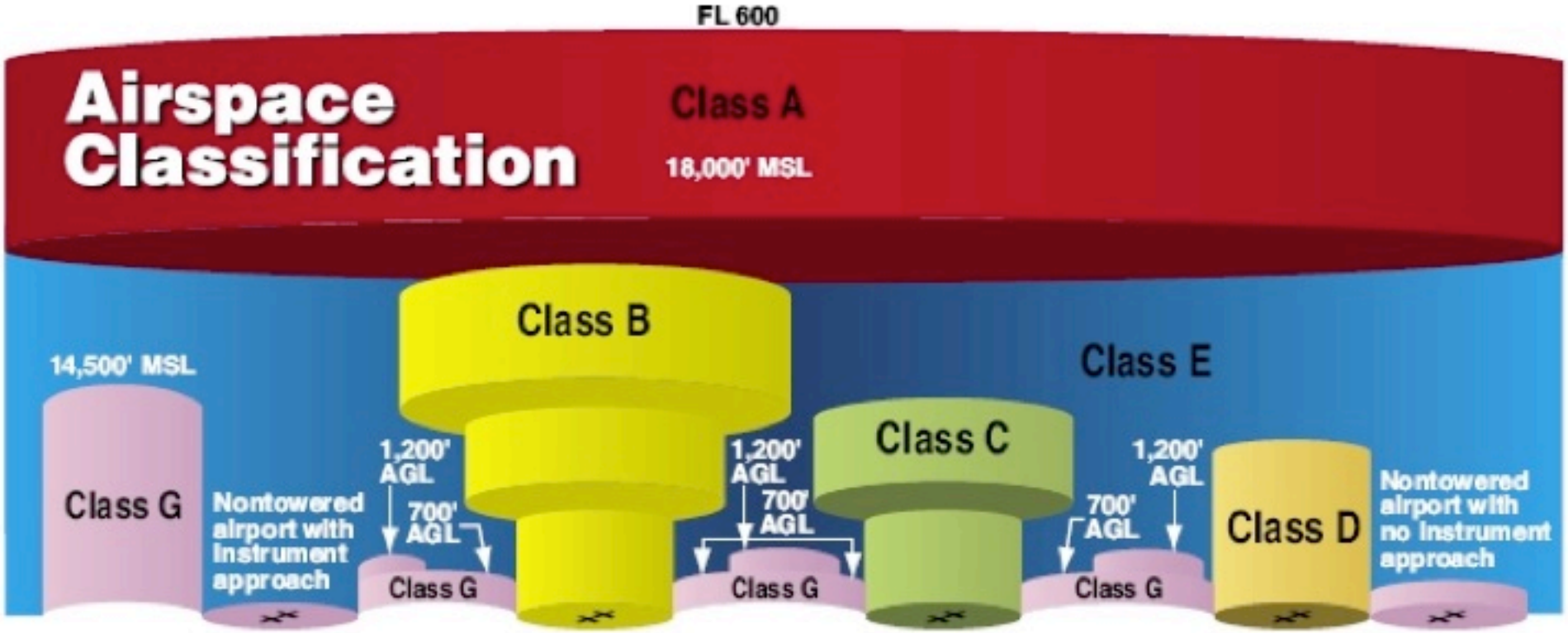
Why use a UAS?

- **Effective for missions that are Dull, Dirty or Dangerous**
  - Humans not put at risk
  - Continuous operations
- **Lower cost than manned aircraft**
- **Presents opportunity for a U.S.-based industry with significant growth and job potential**
  - Increasing Demand for UAS = jobs
  - Manufacturing, training, maintenance, software, etc.
- **United States is a global aerospace leader in terms of safety and technology**
  - Embracing UAS opportunities now will enhance our leadership position
  - Thoughtful, prudent integration will ensure integration risks are accurately identified and properly mitigated

Applications of Unmanned Aerial Systems



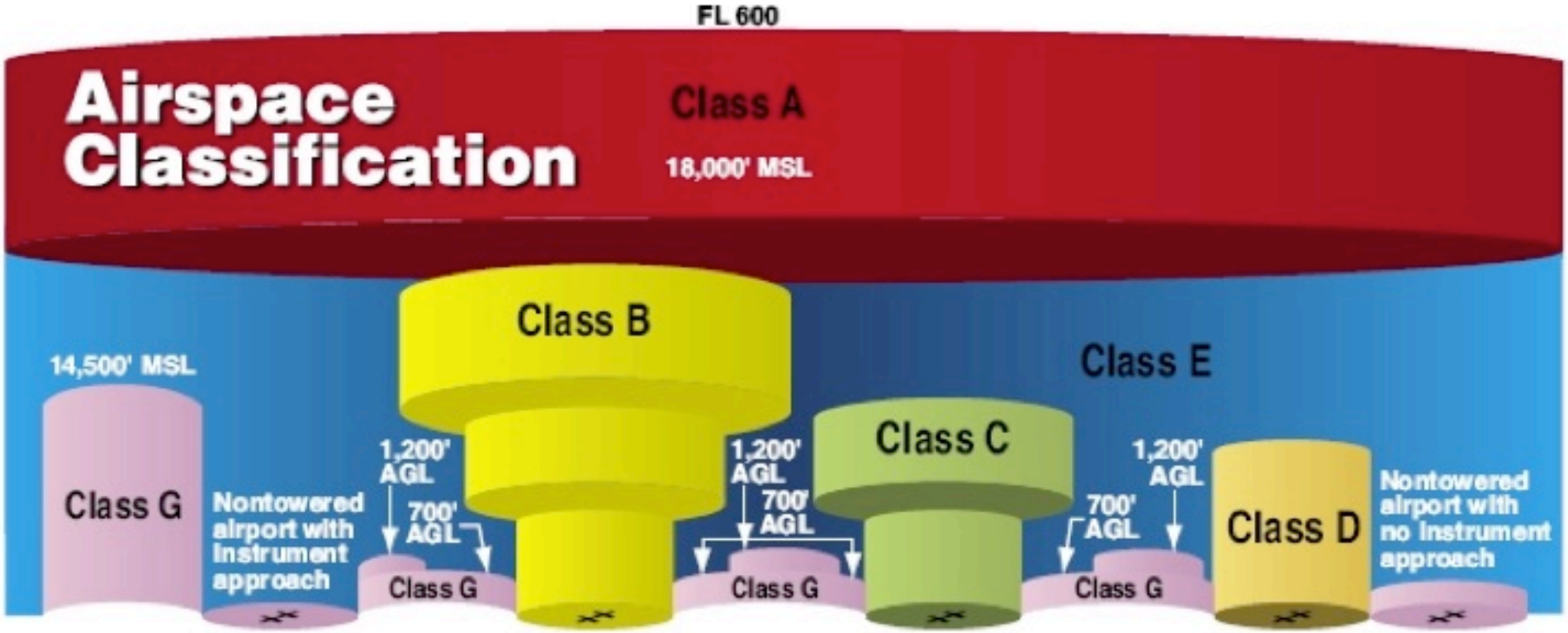
The National Airspace System



Class A

- Highly regulated airspace with jet routes
- UAS would share skies with airliners, military transport and general aviation
- UAS must carry a transponder and report location to ATC
- UAS will operate under Instrument Flight Rules (IFR) and communicate with ATC
- Detect and Avoid technologies are needed to avoid aircraft in an emergency

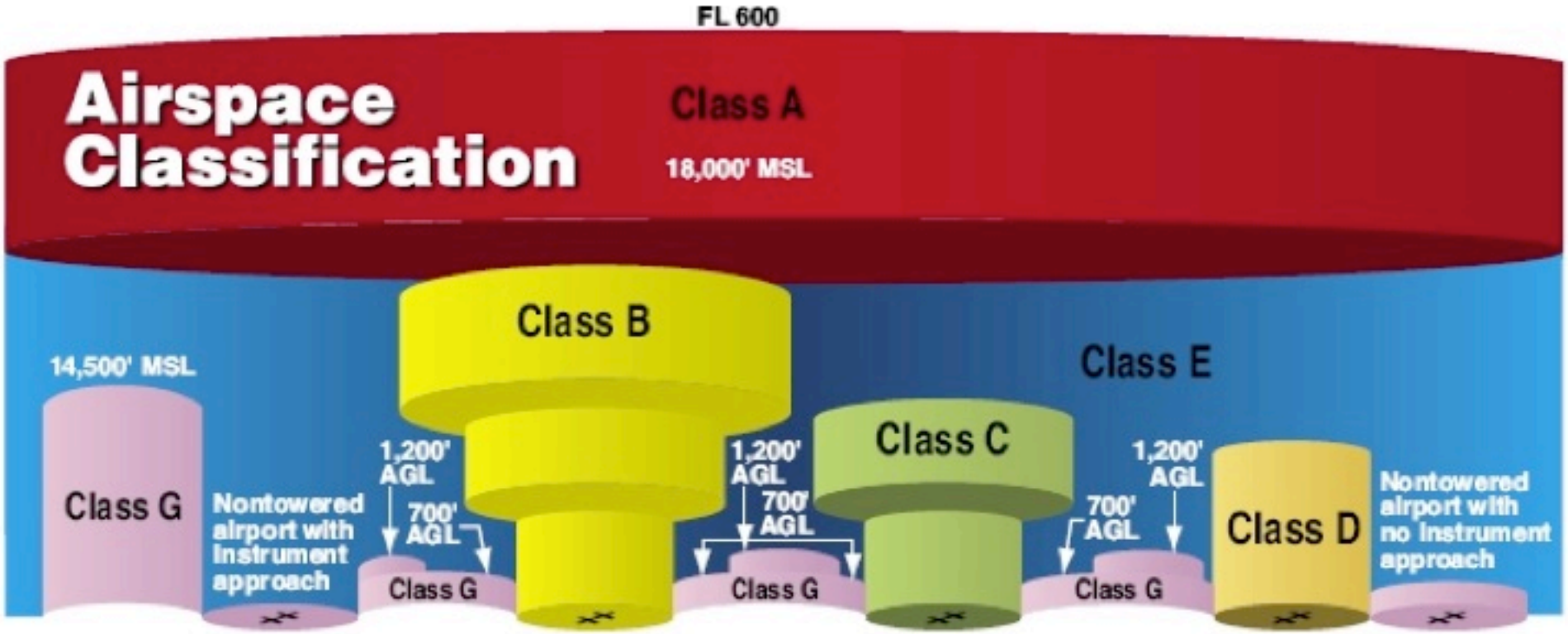
The National Airspace System



Class B,C,D

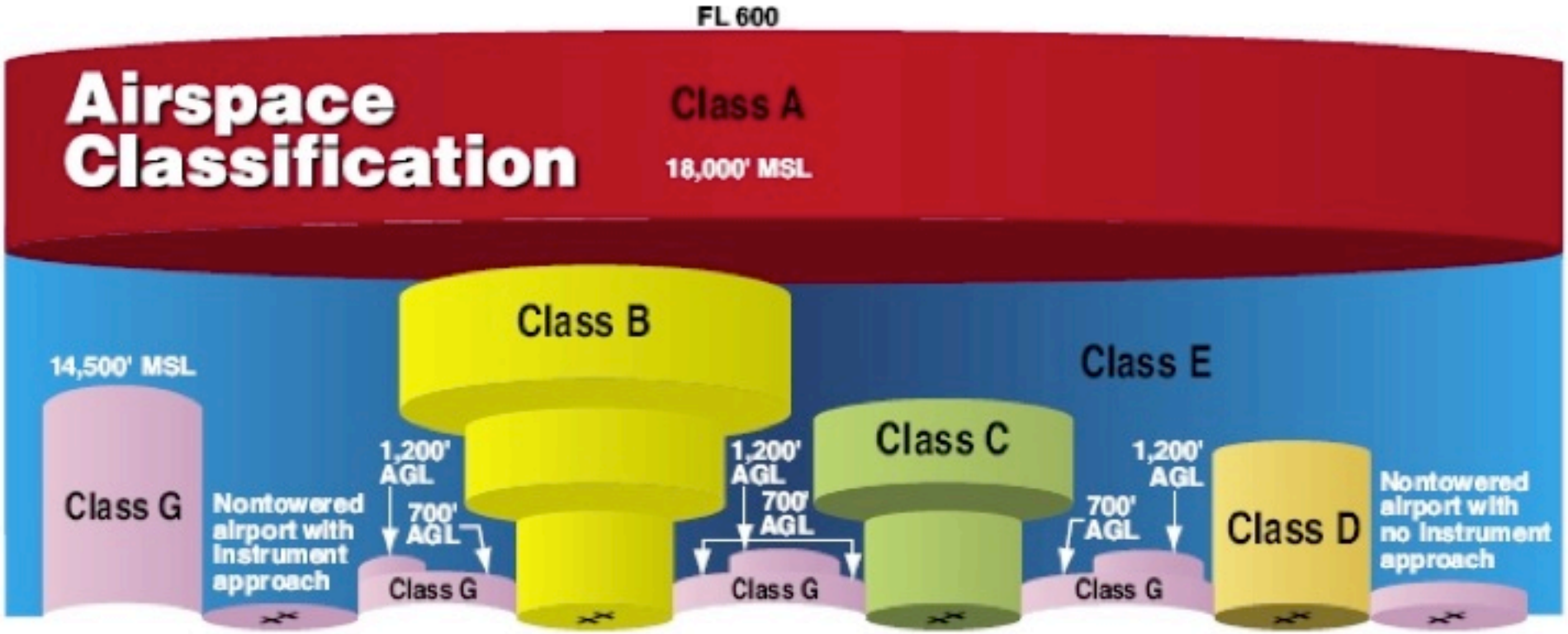
- **Airspace that surrounds airports**
- **Two way communications are required with ATC**
- **Likely all UAS will have to take-off/land under ATC supervision in this airspace**

The National Airspace System



- Above FL 600 holds promise for high altitude long endurance (HALE) UAS **Class E**
- UAS performance differences above FL 600 may cause challenge for detect and avoid
- From 0-18,000 ft in Class E, detect and avoid is complicated by aircraft without transponders and UAS size, weight and power requirements

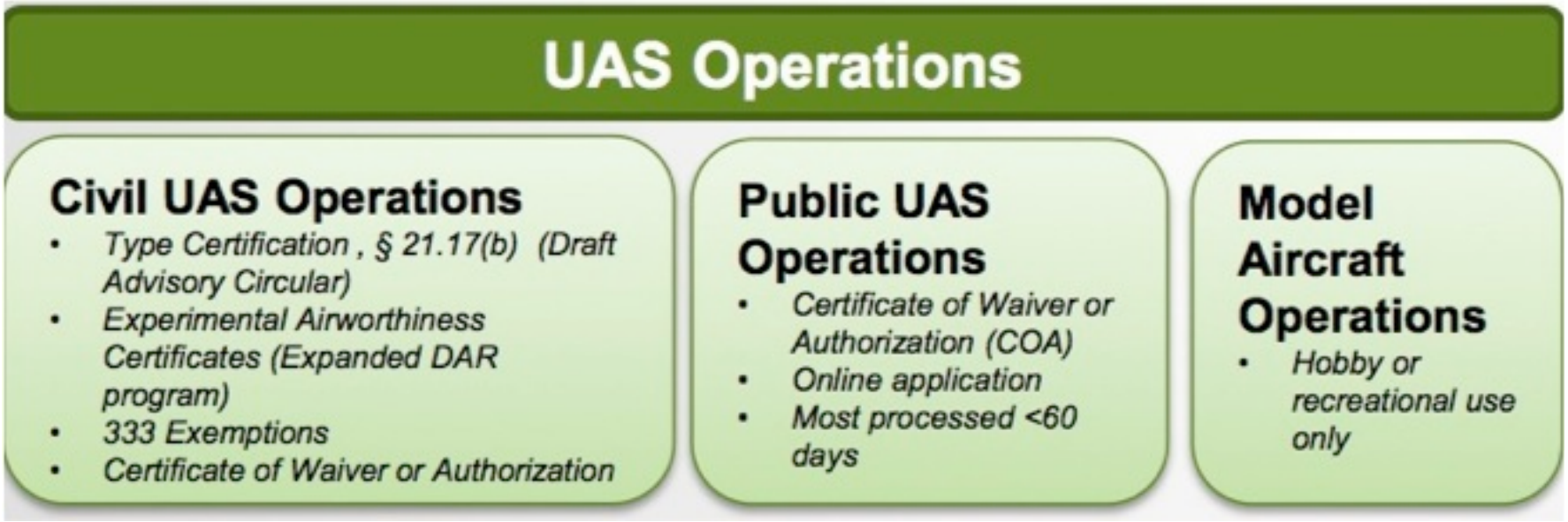
The National Airspace System



- Currently utilized by recreational UAS hobbyist (0-400 ft AGL) within line of sight
- Risk of colliding with helicopters, general aviation, and man-made objects
- Good starting point for UAS Traffic Management

Class G

Is there a legal way to fly UAS in the NAS?



Public UAS Operations

Who is Operating UAS:

- Department of Agriculture
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of Homeland Security
- Department of Interior
- Department of Justice
- NASA
- State Universities
- State/Local Law Enforcement

What are they doing with UAS?

- Border Patrol
- Firefighting
- Disaster Relief
- Search and Rescue
- Training for Ops Missions
- Operational Missions
- Research
- System Development
- Sensor Development & Testing

Civil UAS Operations

Who is Operating UAS:

- 4,731 petitions granted (as of 4/13/2016)

What are they doing with UAS?

- Wide Range of Applications https://www.faa.gov/uas/legislative_programs/section_333/333_authorizations/
- Typical Operations:
  - visual line of sight
  - under 400 ft AGL
  - 2-5 miles away from airport/helipad
  - Daytime operations under visual flight rules
  - 55 lb aircraft and under

Model Aircraft Operations

- Fly below 400 feet and remain clear of surrounding obstacles
- Keep the aircraft within visual line of sight at all times
- Remain well clear of and do not interfere with manned aircraft operations
- Don't fly within 5 miles of an airport unless you contact the airport and control tower before flying
- Don't fly near people or stadiums
- Don't fly an aircraft that weighs more than 55 lbs
- Don't be careless or reckless with your unmanned aircraft

Integrating UAS into the U.S. National Airspace System

Key Organizations

Congress
FAA Modernization and Reform Act of 2012 – Sections 331-336

ExCom
FAA, DoD, NASA, DHS

UAS Strategic Working Group
Advances cross-Agency UAS integration activities

FAA UAS Integration Office
Agency focal point for all things UAS

Communication and Outreach

- *Know Before You Fly* Outreach Campaign (FAA/Industry)
- Law Enforcement Guidance
- FAA Media Outreach
- FAA UAS Integration Office Website (www.faa.gov/uas)

UAS Operations

Civil UAS Operations
- *Type Certification , § 21.17(b) (Draft Advisory Circular)*
- *Experimental Airworthiness Certificates (Expanded DAR program)*
- *333 Exemptions*
- *Certificate of Waiver or Authorization*

Public UAS Operations
- *Certificate of Waiver or Authorization (COA)*
- *Online application*
- *Most processed <60 days*

Model Aircraft Operations
- *Hobby or recreational use only*

Regulatory Actions

Section 333 Exemptions
- *Bridge to small rule*
- *Robust interest*
- *FAA streamlining process*

FAA Small UAS Rulemaking
- *NPRM Published*
- *Comments due April 24, 2015*

Special Rule for Model Aircraft (Section 336)
- *FAA Interpretive Rule published June 25, 2014*

Industry & International Engagement

- **UAS Aviation Rulemaking Committee** – *Informs FAA Rulemaking Approach*
- **RTCA Special Committee 228** – *Industry design standards for Detect and Avoid and Command and Control systems*
- **ASTM International Committee (F38)** – *Industry standards for small UAS*
- **UAS Center of Excellence (future)** – *Short- and long-term UAS research*
- **ICAO** – *International UAS Standards Development*
- **JARUS** – *International UAS Standards Development*

UAS Test Sites

Site specific UAS DARs designated to issue A/W Certificates.

- University of Alaska
- North Dakota Department of Commerce
- Texas A&M University Corpus Christi
- State of Nevada
- New York's Griffiss International Airport
- Virginia Polytechnic Institute & State University

Integration Challenges

Technology

Detect and Avoid
Command and Control
Human Factors / Autonomy
Contingency Management
Size, Weight, and Power
GPS-Denied Environment
Security

Regulation

Airworthiness
Certification
Registration
Safety Case
Separation Standards
Operational Flight Rules

Public Acceptance

Perception of risk, benefit and capability
Privacy, Liability, Admissible Evidence (Legal)
Ethics
Noise/Environment
Politics and Media

Economics

Business Model
Size of Market
Volume and Demand
Market Inertia
Market Entry Strategies
Return on Investment

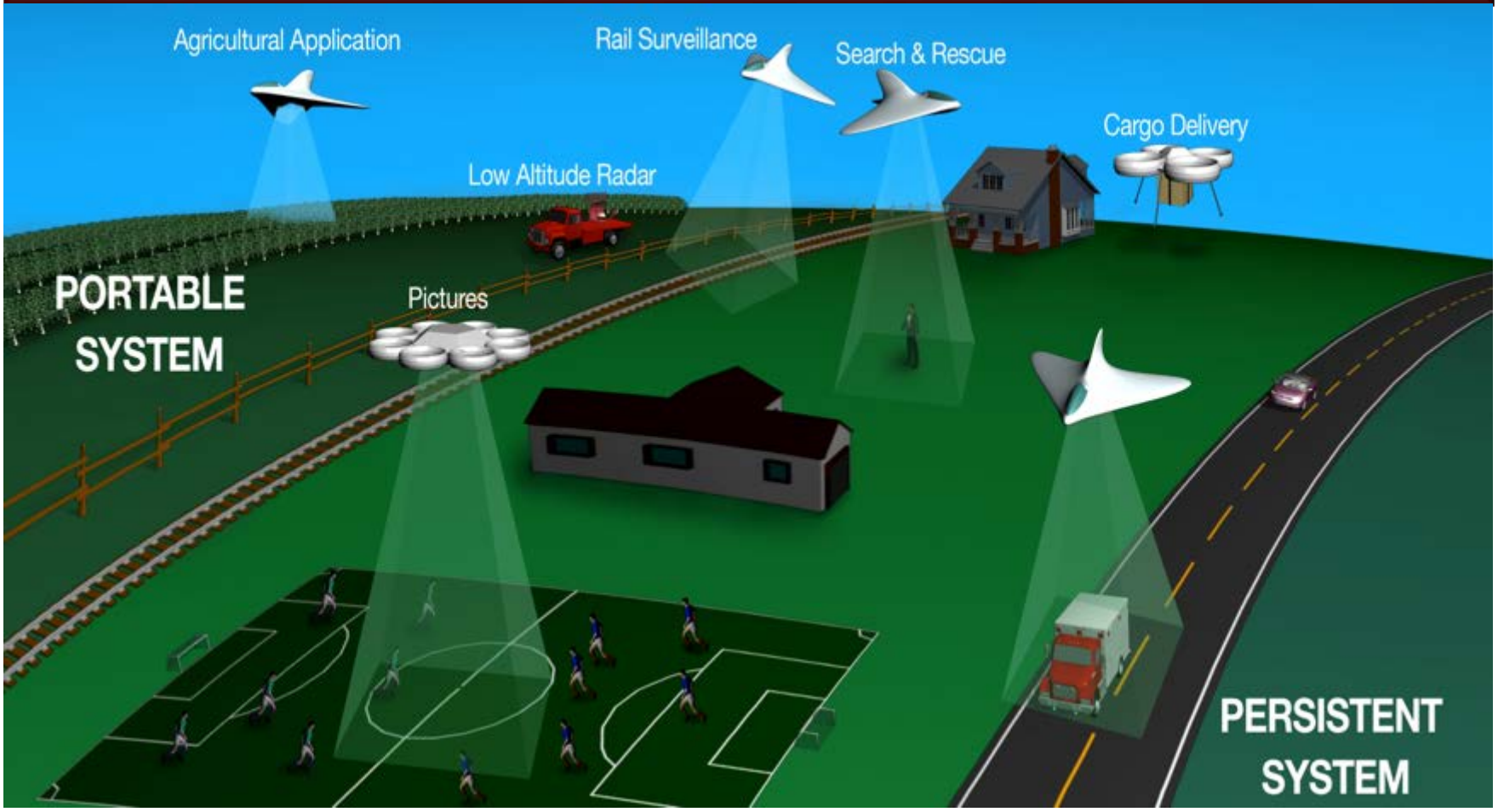
Grand Canyon June 1956

Security Pacific National Bank Collection / Los Angeles Public Library Photo Collection

Unmanned Aerial System Traffic Management (UTM)

Near-term Goal: Safely enable initial low-altitude UAS as early as possible

Long-term Goal: Accommodate increased demand with highest safety, efficiency, and capacity



Challenge and Opportunities

- Challenge: Acceptance of large-scale UAS operations in low altitude airspace
  - Airspace operations requirements: technology and procedures
  - Safety
  - Privacy policy
  - Security
  - Noise
  - Public perception
- Economics: Safe, secure, and scalable “Beyond visual line of sight” operations
- Opportunities: Technology advancements and new business models

UAS: Balancing Multiple Needs

National and Regional Security

Protecting key assets

Safe Airspace Integration

Flexibility where possible and structure where needed

Geographical needs, application, and performance-based airspace operations

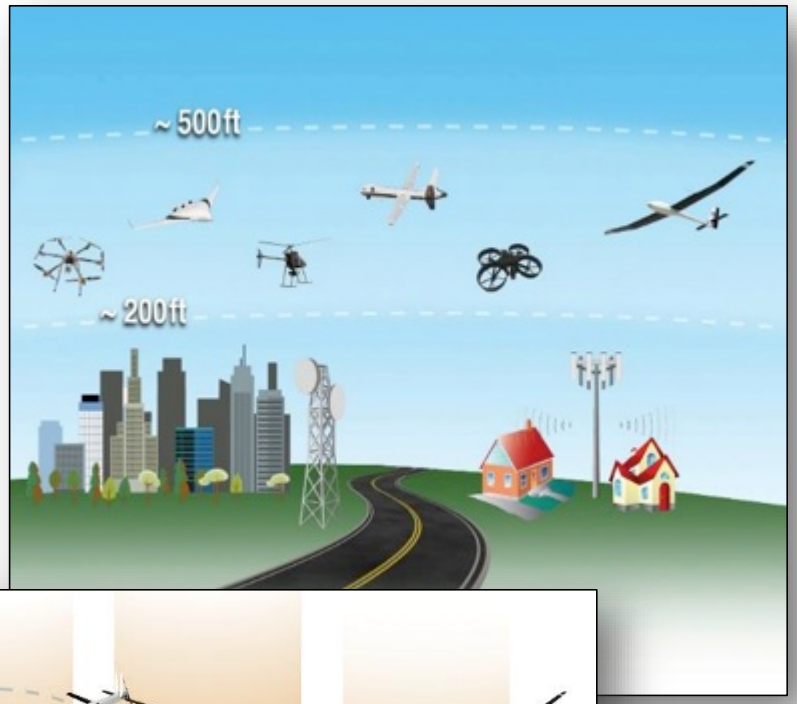
Scalable Operations for Economic Growth

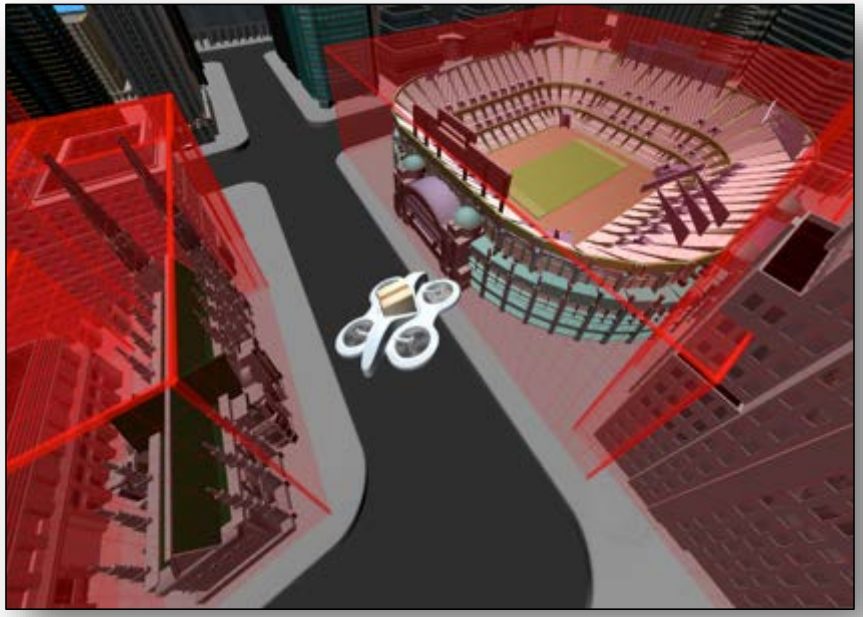
Ever-increasing applications of UAS: Commercial, Agricultural, and Personal

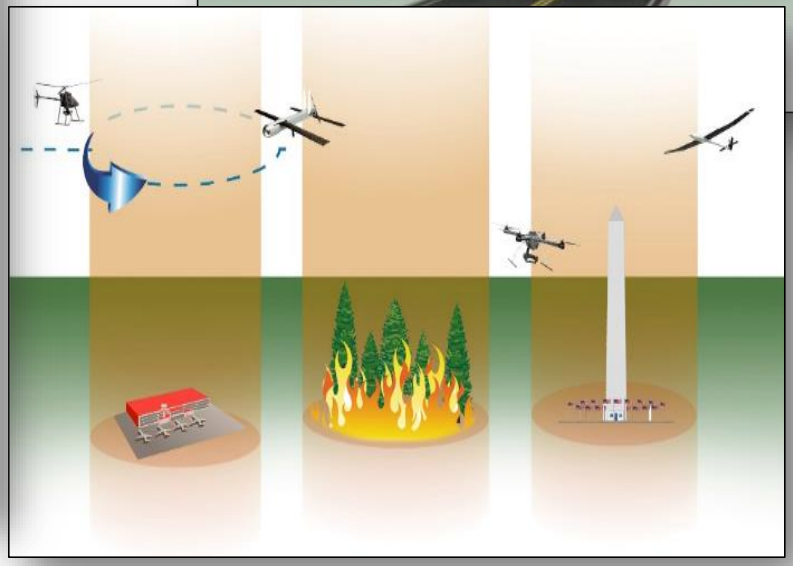
UTM Functions

AIRSPACE OPERATIONS & MANAGEMENT

- Geographical needs and applications
- Rules of the airspace: performance-based
- Geofences: dynamic and static
- Consider other traffic and underlying environment







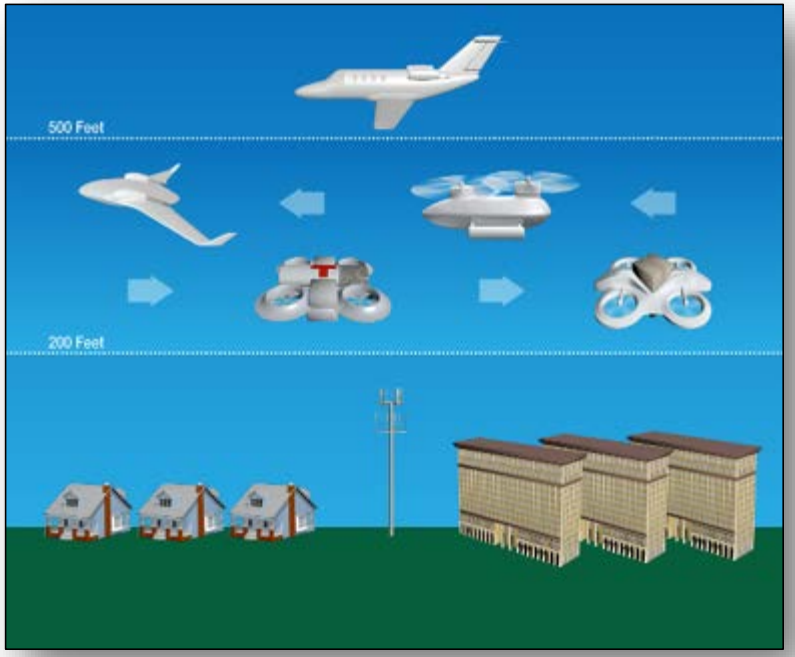
UTM Functions

Wind & Weather Integration

- Actual and predicted winds/weather

Congestion Management

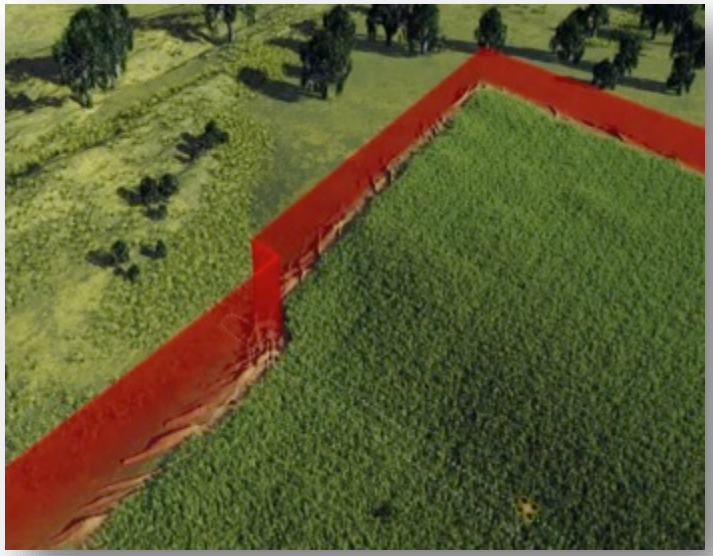
- Demand/capacity imbalance
- Only if needed – corridors, altitude for direction, etc.



UTM Functions

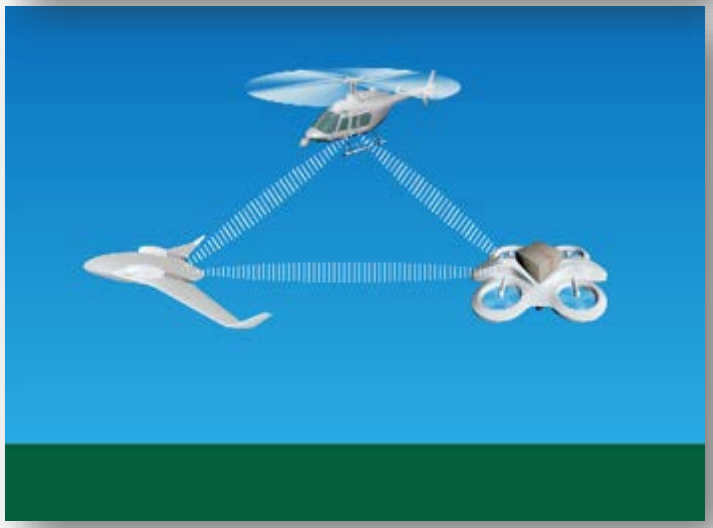
Separation Management

- Airspace reservation
- V2V and V2UTM
- Tracking: ADS-B, cellphone, & satellite based



Contingency Management

- Large-scale GPS or cell outage
- 9-11 like situations



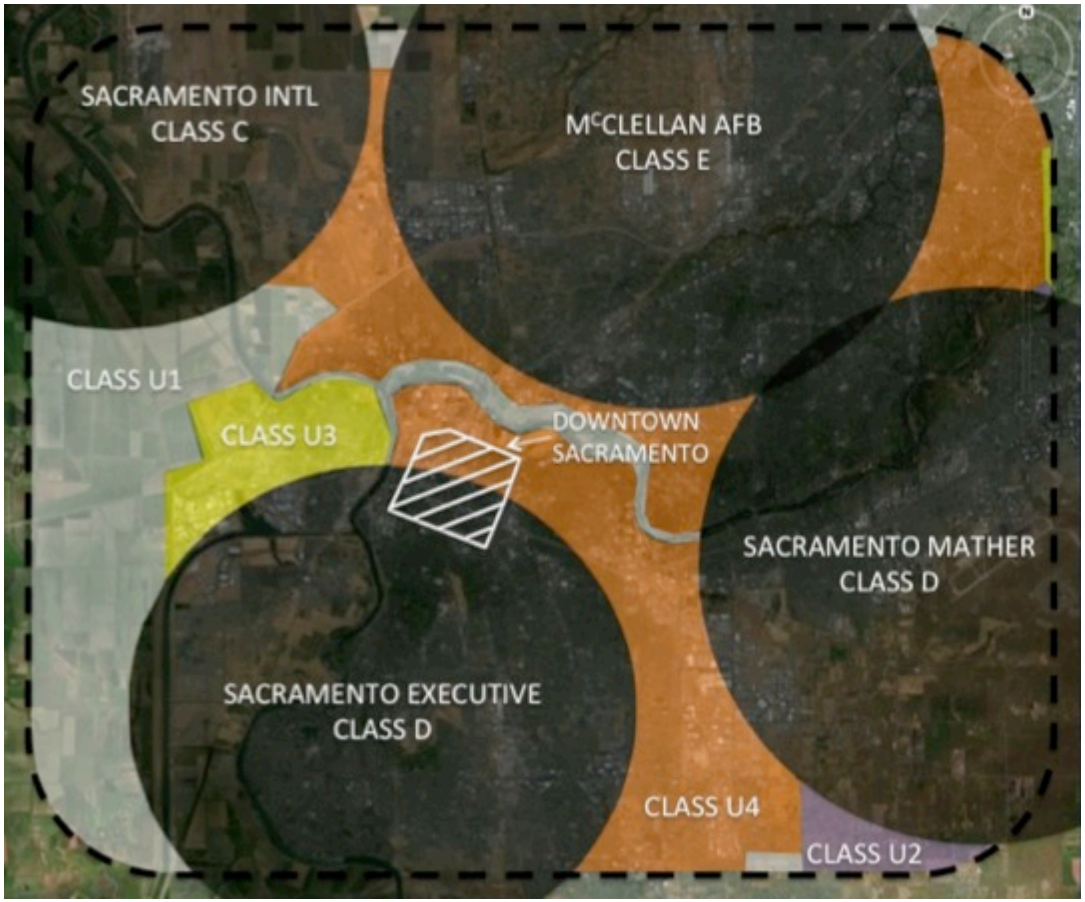
Airspace Managed by UTM

Based upon four risk-based criteria:

- **Population Density**
- **Density of Man-made Structures**
- **Likelihood of Manned Operations**
- **Number of UTM operations**

Bounded by

- **Jurisdiction and Airspace Management Authority**
- **UTM Connectivity**



Terrain Maps | User Credentials | Public Safety Data | Surveillance Data
Obstacle Data | Airspace Data | Vehicle Registration
Weather Data | NOTAM Data | Vehicle Performance

Data Service Providers

Air Traffic Controllers

Air Traffic Managers

UTM API

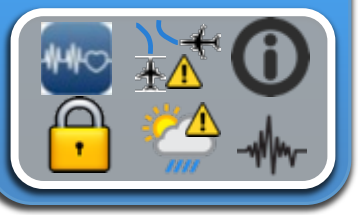
Other USS

UTM API

UTM Manager GUI

UTM Manager

USS Services



UAS Service Supplier (USS)

Hobbyists

General Public

Air Traffic Systems
Traffic Management Systems
ATC System Command Center
Airport Tower

ATM Systems

UTM API

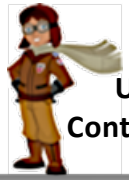
Regulatory Agencies
Law Enforcement
Public Access
Community Groups

Other Stakeholders

UTM API

UAS

UAS Controllers



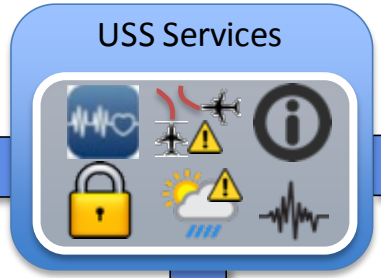
UTM Clients

UAS Operators

UAS Operations

Public Safety | USS Operations
Precision Agriculture | Science Missions

USS Services



- System Health Monitoring
- Vehicle Registration
- User Authentication
- Flight Monitoring

Security Services

- Flight Planning
- Scheduling and Demand Management
- Separation Assurance
- Contingency Management
- Spectrum Management

Flight Services

- Airspace Definition
- Weather Information
- Terrain and Obstructions
- Traffic Operations

Information Services

TCL 1: August 2015

Line of Sight Operations
Low Risk Environment
Airspace Reservation
Geo-fencing for Separation
No Fly Zones
User Authentication

TCL 2: October 2016

Beyond Line of Sight Operations
Low Risk Environment
Segmented Flight Plans
Weather and Traffic Advisories
Altitude Stratification
Contingency Management (Alerting)
System Health Monitoring

TCL 3: January 2018

Beyond Line of Sight Operations
Suburban Environment
In-Flight Separation Provisions
Contingency Management (Resolutions)
On-demand Public Service Operations
Spectrum Management
Interacting UTMs
Limited Connections to ATM
Weather and Traffic Avoidance

TCL 4: March 2019

Beyond Line of Sight Operations
Urban Environment
Detect and Avoid
GPS-Denied Environments
Large Scale Contingency Management
Dynamic Airspace Reconfiguration
High Density Operations

TCL 1 UAS Operations

Manufacturing
- EM Tower Inspection
- Wind Turbine Inspection
- Bridge Inspection
- Power Line Inspection
- Solar Panel Inspection
- Rail Inspection
- Landfill Inspection
- Pipeline Inspection
- Dam Inspection
- Canal Inspection
- Waterway Inspection
- Water Tower Inspection
- Petroleum Spill Monitoring

Farming
- Aerial Application
- Precision Agriculture
- Livestock Monitoring
- Invasive Plant Monitoring

Other
- Forest Management
- Mosquito Monitoring
- Wildlife Conservation
- Archaeology
- Anthropology
- Prospecting

Oceanic
- Maritime Surveillance
- Maritime Scouting
- Ocean Research
- Anti-Piracy

Recreation
- Animal Spotting for Hunting
- Nature Photography
- Adventure Sports Photography

<u>Typical Operation Limitations</u>

Line of Sight Operations

Typically <400 ft AGL

VMC Conditions & Daylight

UAS < 55lbs

500 ft away from structures

1 UAS Operator submits operational plan

Schedule Crop Monitoring of Farm X

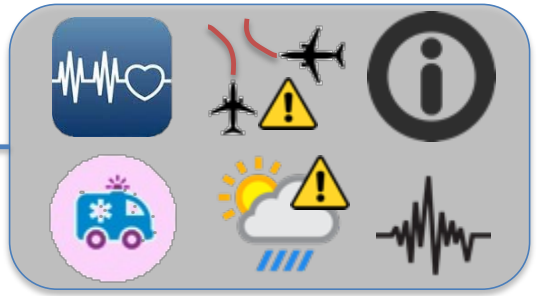
2 Vehicle registration checked

Vehicle Performance and Registration Database

5 UTM reports no issues and UAS operation begins

3 Static constraints are checked

UTM



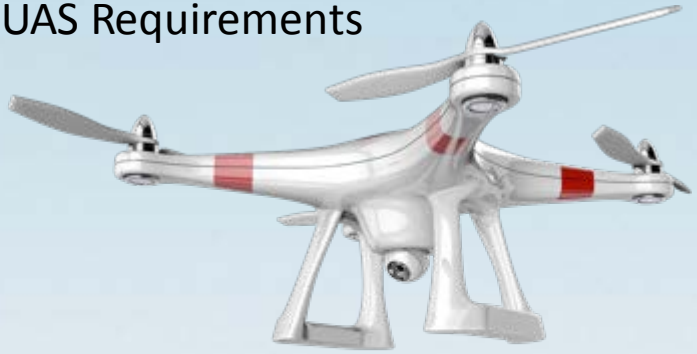
6 UTM Services are provided during operation

4 Dynamic constraints are checked

7 UAS operation completes

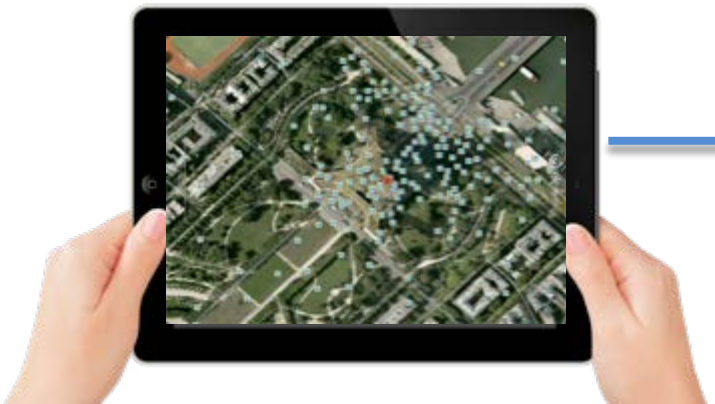
Operational Rules and Guidelines

UAS Requirements



CNS Requirements

Airspace Management Requirements



Data Services, Interfaces, and Architecture Requirements

NASA UTM Project Objectives

Airware ne³rd

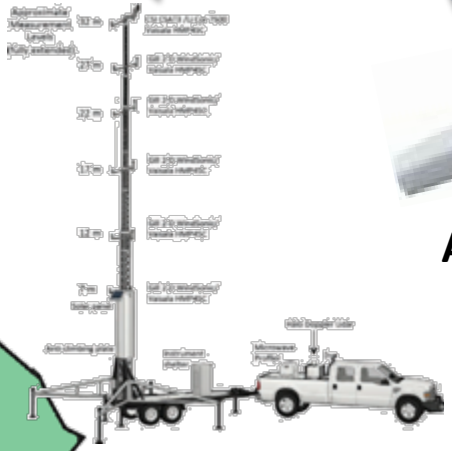
PRECISIONHAWK UNMANNED EXPERTS

SKYSPECS

LONE STAR UAS CENTER OF EXCELLENCE & INNOVATION

Simultaneous UAS Operations

Aug. 24 – Sept 1st, 2015
~ 108 Flights
~18 Flight Hours
Duration: 2-38 minutes
Avg. Flight Time: ~ 11 min



Weather Sensors

San José State UNIVERSITY

Acoustic Sensors

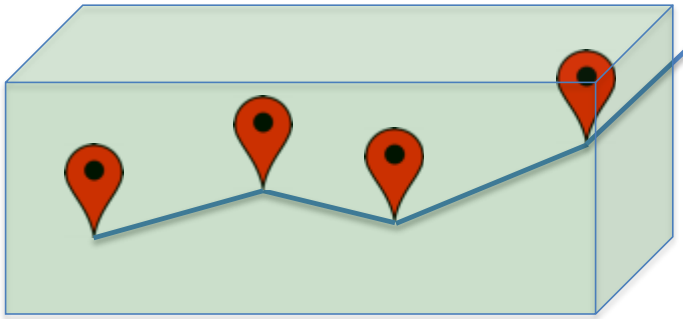
Surveillance Sensors

GRYPHON SENSORS™ a subsidiary of SRC, Inc.

verizon EXELIS

Demonstration Objectives

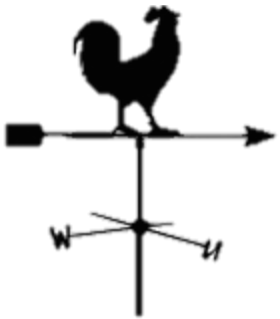
Objective 5: Collect Data on Noise Signature of UAS Vehicles



Objective 2: Collect Data on UAS Navigation Performance Error

Objective 1: Demonstrate UTM Capabilities

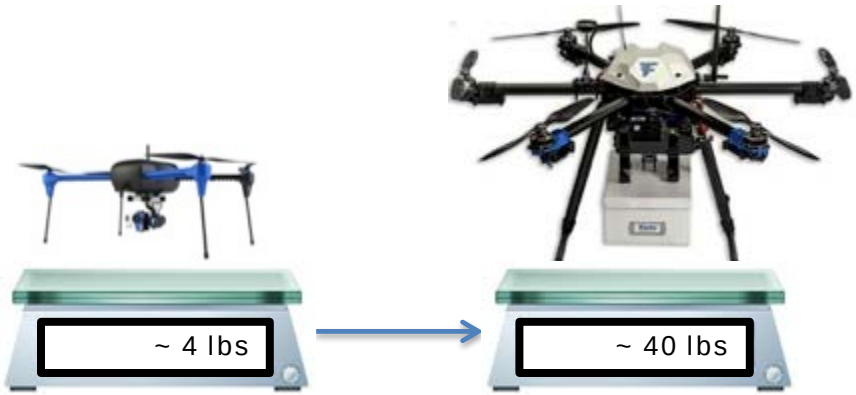
Objective 3: Collect Data on Aircraft Tracking Performance



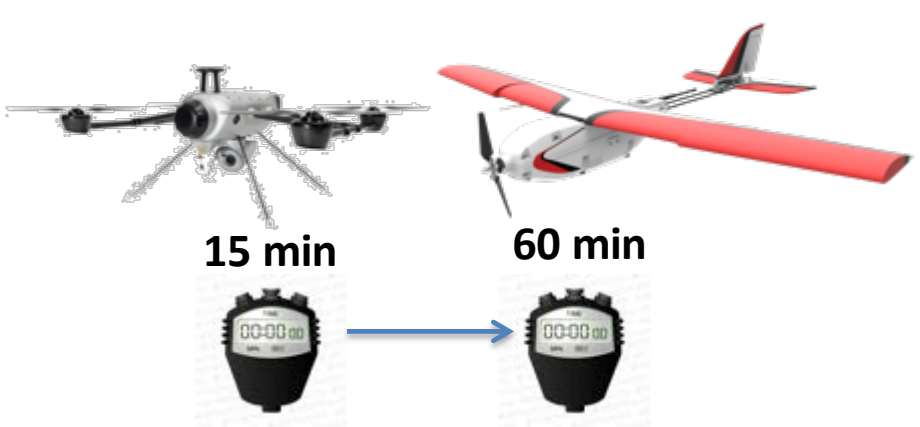
Objective 4: Collect Weather Observations for Forecasting Models

UTM Vehicles

8 multi-rotors and 2 fixed wing



Maximum Take-off Weight



Endurance

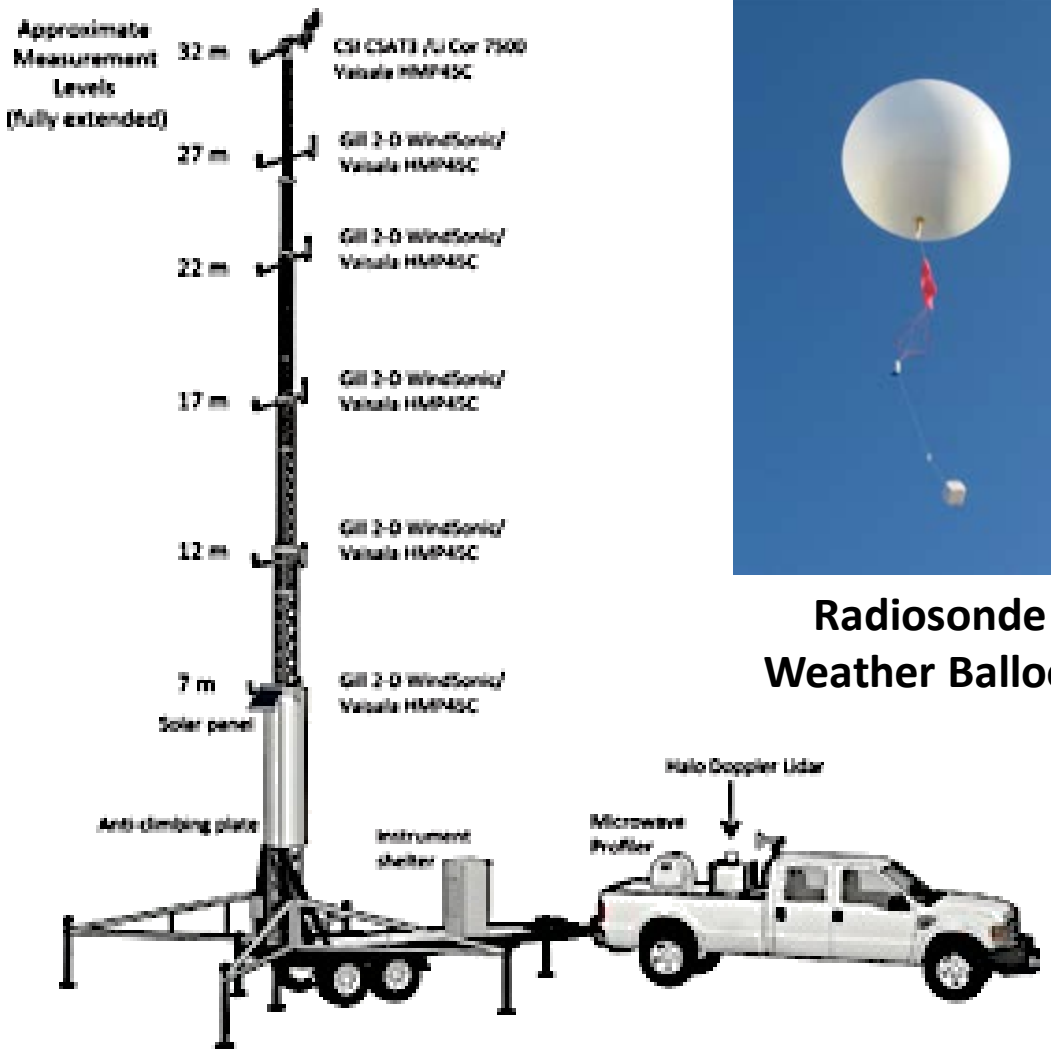
UTM Manager Displays

Java-based Desktop Display

iOS Application

UTM Field Equipment : Weather

Weather Tower



Radiosonde Weather Balloon

Data Collected

- Temperature
- Pressure
- Wind Direction
- Wind Speed
- Altitude
- Turbulent Kinetic Energy

Remote Automated Weather Station

UTM Field Equipment : Surveillance and Acoustics

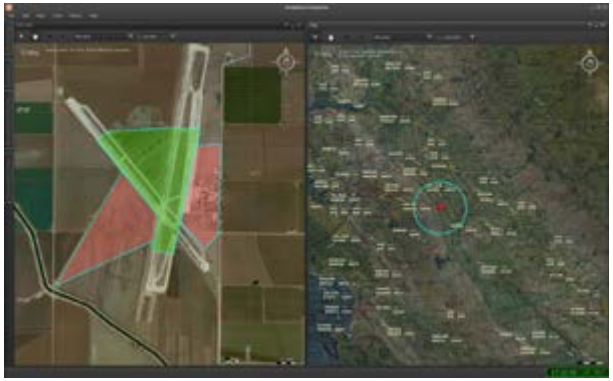
Short Range Radar

Cellular Network Tracking

Data Collected

Latitude
Longitude
Altitude
Sound magnitude and frequency

ADS-B Out Transponder



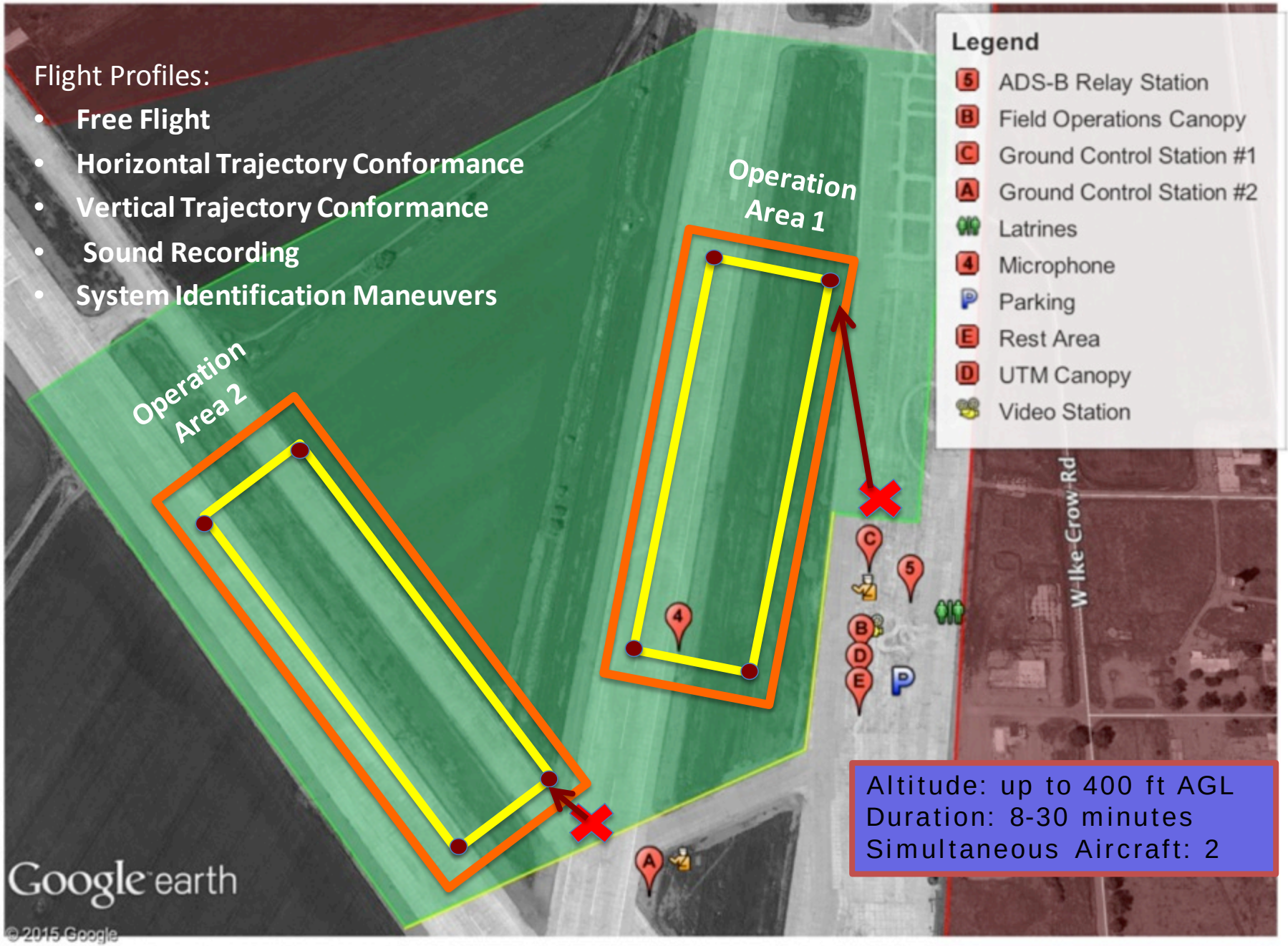
Ground Situation Awareness Display (ADS-B In, En Route radar, Terminal Radar, ASDE-X, ASSC)

Acoustic Measurement

Nicolet Vision XP

B&K Nexus
4-Ch Power Supply

½” B&K
Microphone
+ Wind Screen



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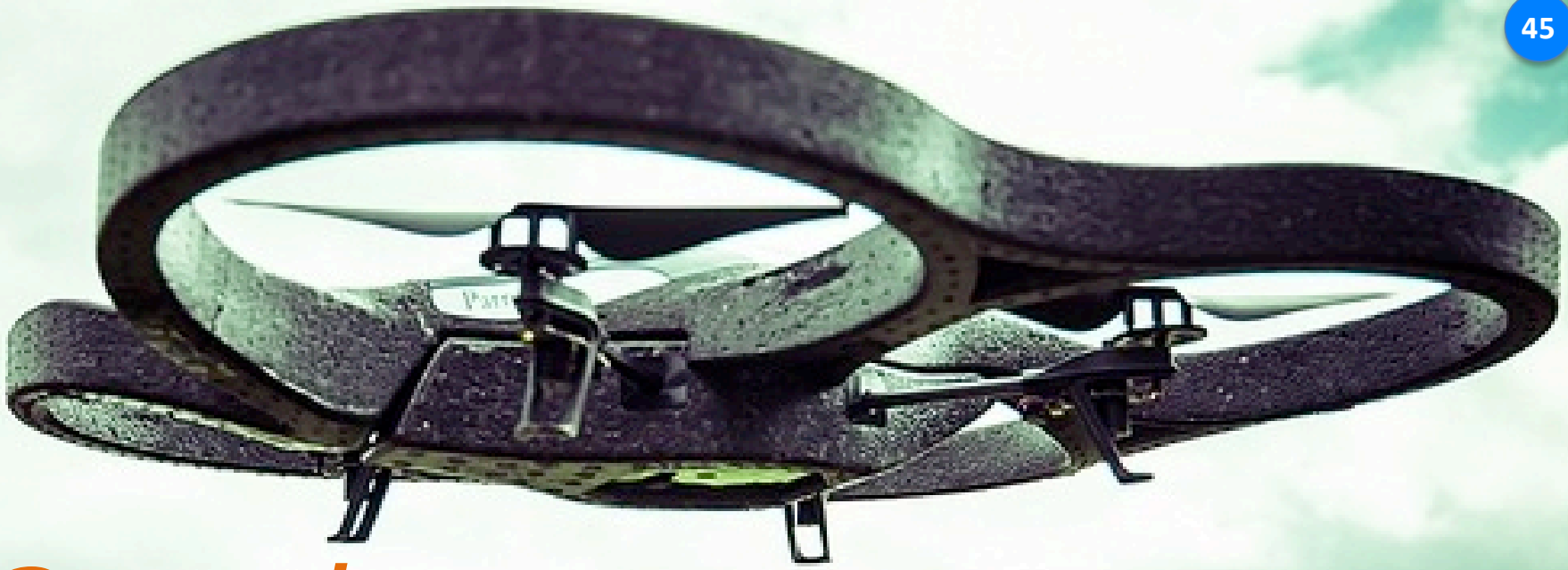
Observations of Operational Use

- *New Airspace Users will require training and UTM needs to be intuitive*
  - **Observation:** UAS Operators submitting an operational plan to the system that differs from what was input into the GCS or a willingness to violate an operational plan.
  - **Recommendation:** Operator training and integration of flight planning and traffic management services into ground control stations

- *The right equipment for the operational environment*
  - **Observation**: High temperatures had impact on ground equipment. C2 interference occurred with local farming equipment. Degradation of GPS signals impacted flight operations.
  - **Recommendation**: UAS and ground systems and instruments are "qualified" by operational environment and performance.

- Situation awareness is key for safe operations
  - **Observation**: sUAS varies with size and line of sight (LOS) can be easily lost (e.g. sUAS looked like birds during operation). Weather reported on the ground isnt always indicative of weather experienced at operational altitude. Tracking of sUAS needs to occur at sufficiently fast update rates.
  - **Recommendation**: Improvements are needed in weather forecasting, modeling, and sensing at low altitudes. Tracking UAS infrastructure will need to be built to scale and with sufficient bandwidth. Airspace users should be given a common picture of their environment for safe operations.



Questions

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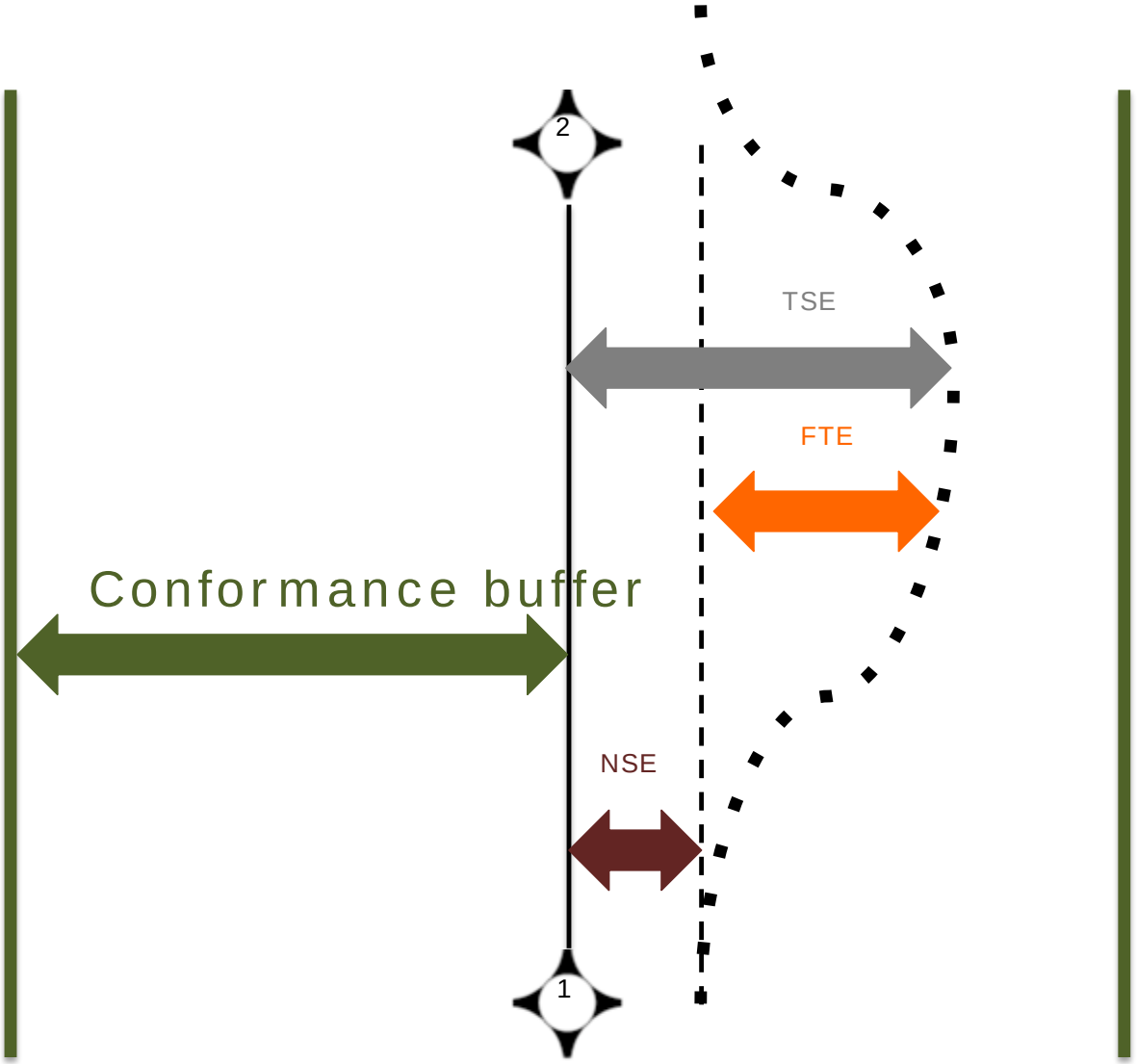
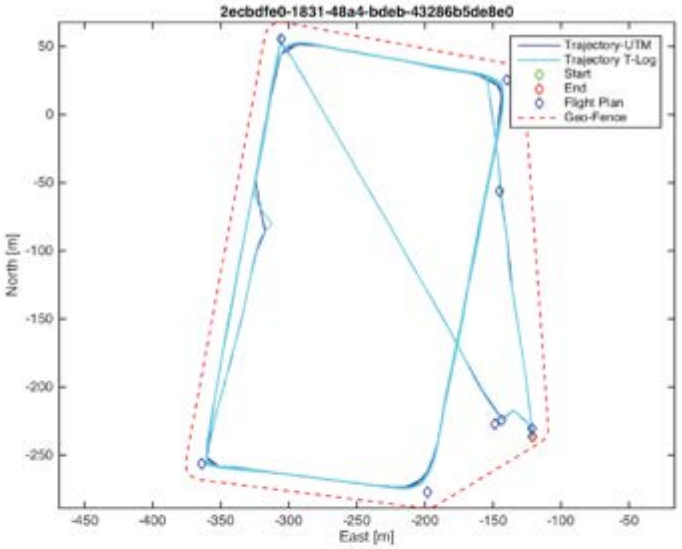
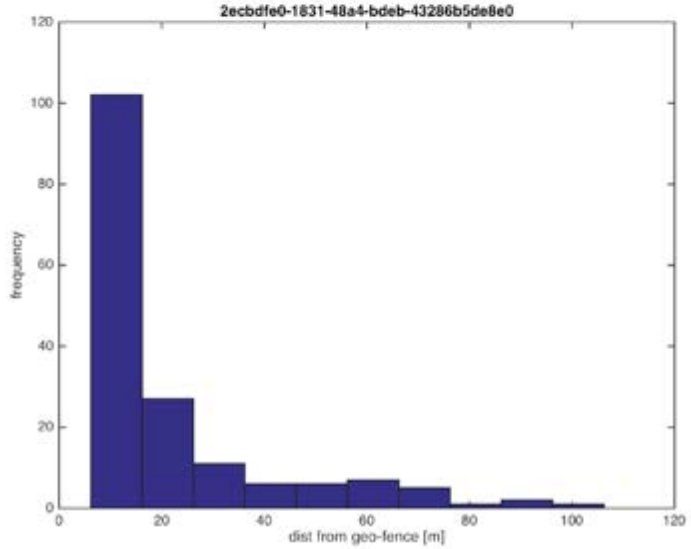
System Error

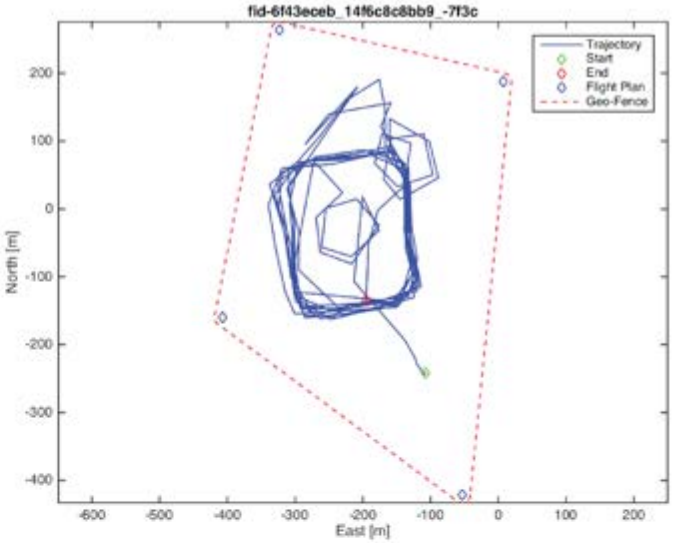


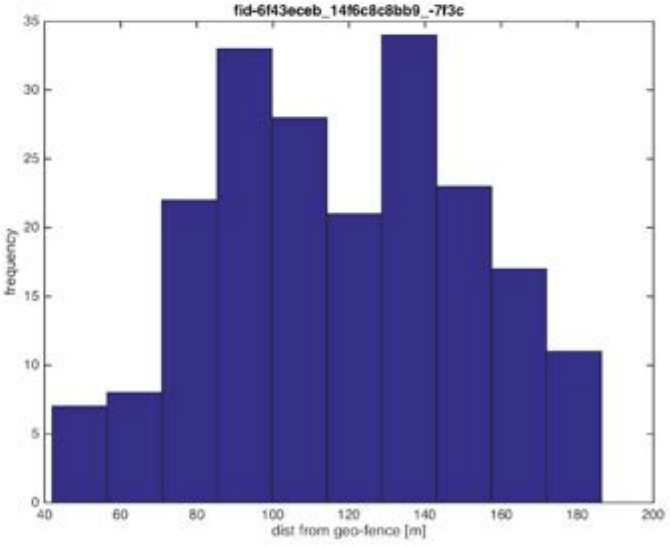
Sample Results: Conformance to Flight Plan



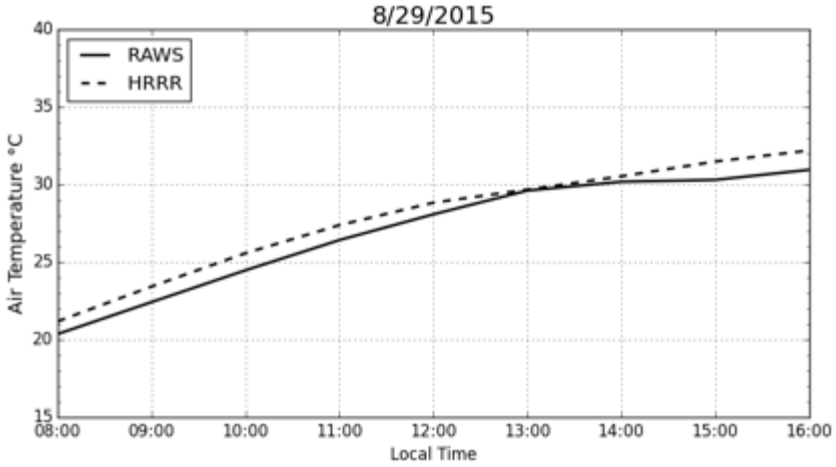


Sample Results: Determination of Buffer for Operational Area

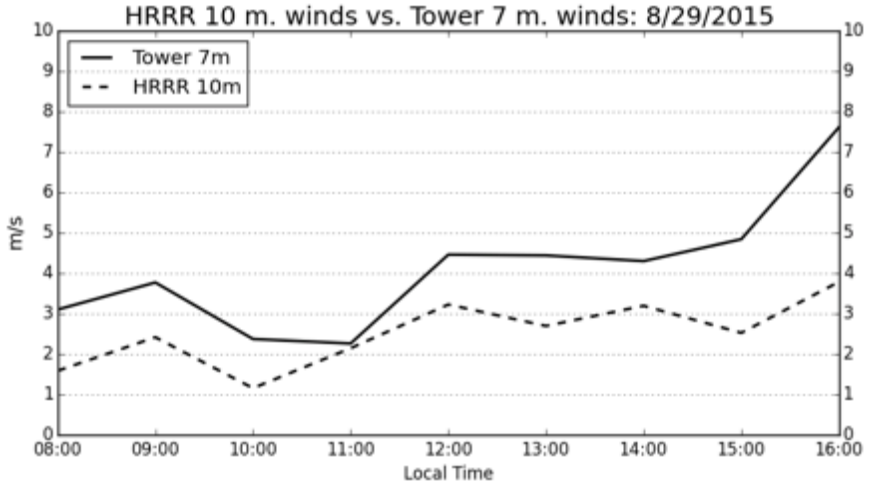




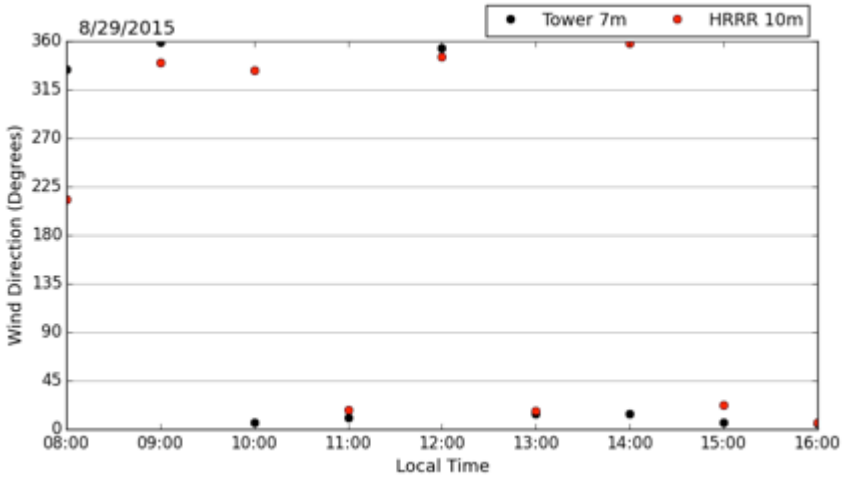
Sample Results: Weather Comparison to HRRR



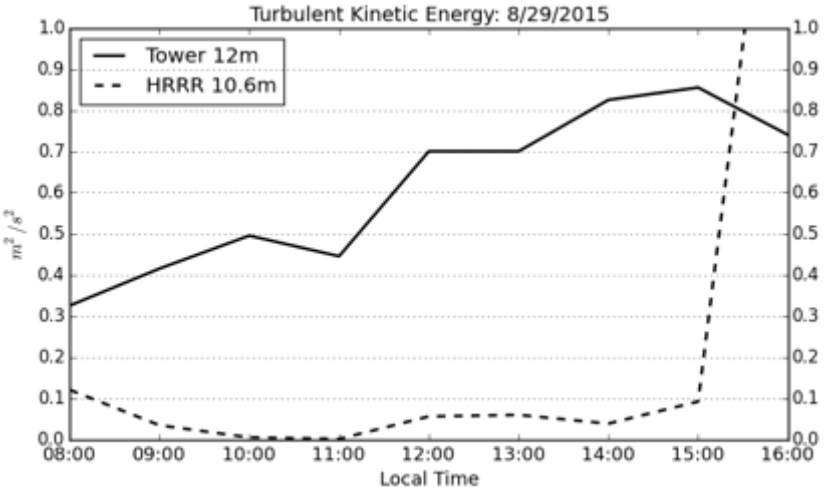
Temperature



Wind Speed



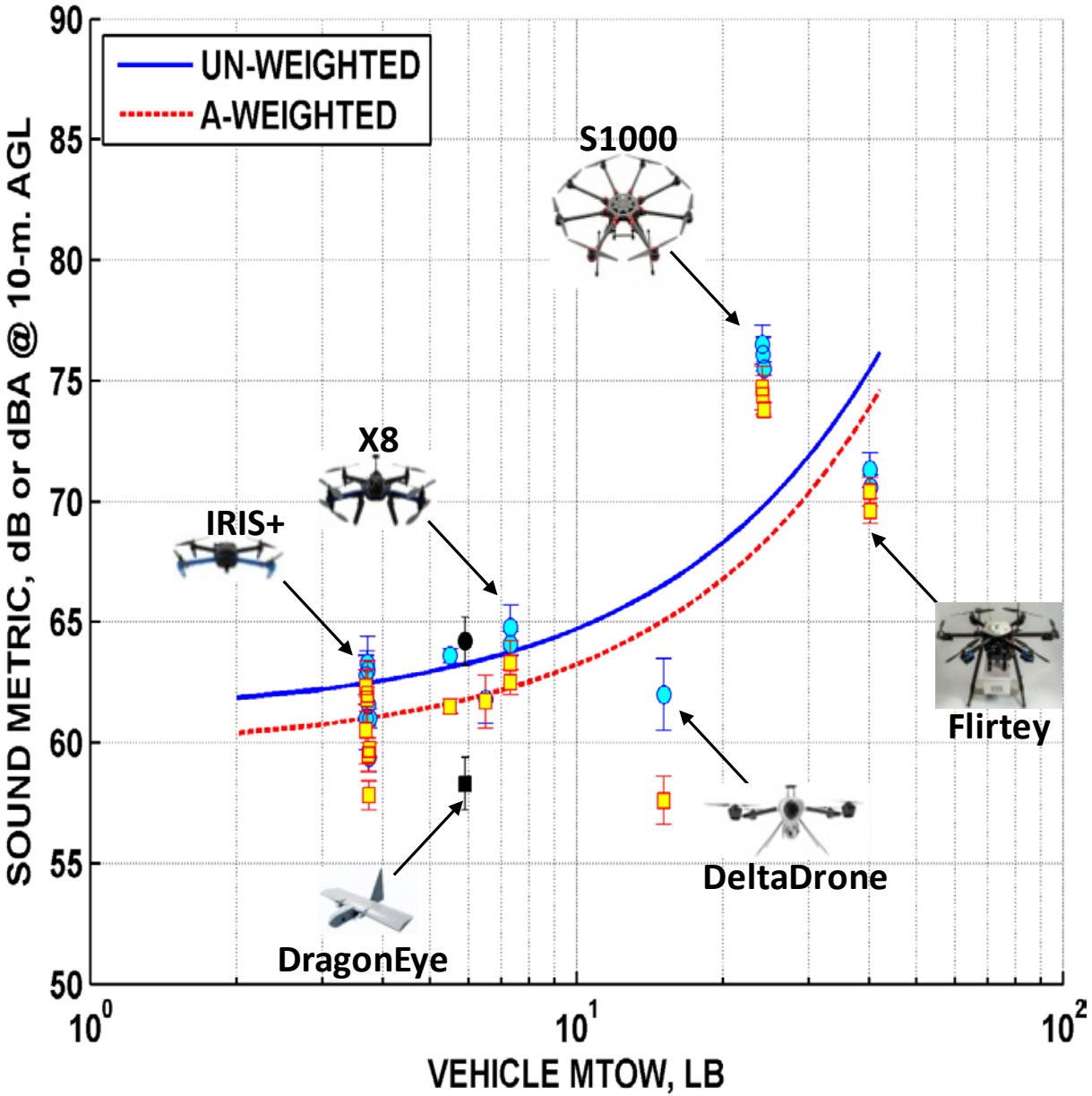
Wind Direction



Turbulent Kinetic Energy

Sample Results: Vehicle Sound Profile

- **Scaled to 10 m AGL.**
- **Plotted as a function of MTOW** → not weight as tested!
- **Under 10 lb group clusters around 60 – 65 dB**
- **Over 10 lb group has no definitive trend with MTOW**
- **Fixed-wing DragonEye has comparable noise level as the quads.** Surprised!



Sample Results: Relative Sound Footprint

- **Sound Exposure Level (SEL) scaled to 500-ft AGL.**
- **UAV data plotted as a function of MTOW** → not weight as tested!
- **UAVs cluster around 40 – 50 dB** → below conversation level
- **FAA data for light helos are 30 – 40 dB higher**